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## EPOXY-RESIN CABLE TERMINATIONS

BY PETER B. KELLER

UNDERWATER SYSTEMS DEPARTMENT

3 FEBRUARY 1989

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# FOREWORD

This report documents an initial investigation into the application of epoxy-resin terminations, or end-fittings, to small diameter cables. Test samples were made using steel, titanium, and amorphous metal cable. Tensile tests produced results usually equal to the ultimate tensile strength of the cable. A significant amount of work remains to be done, however, and this report is intended to serve as a progress report which includes sufficient information to facilitate the continuation of this work at a convenient time.

Approved by:

*Betty H. Gay*

BETTY H. GAY, Head  
Underwater Systems Department

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## CONTENTS

<u>Chapter</u>		<u>Page</u>
1	INTRODUCTION .....	1
	BACKGROUND .....	1
	REPORT OVERVIEW .....	1
2	PREPARATION OF SPECIMENS .....	3
	MATERIALS .....	3
	METHODOLOGY .....	3
3	TESTING AND EVALUATION .....	11
	TESTING .....	11
	EVALUATION .....	11
4	CONCLUSIONS .....	17
5	RECOMMENDATIONS .....	19
	PREPARATION OF SPECIMENS .....	19
	TESTING AND EVALUATION .....	19

## ILLUSTRATIONS

<u>Figure</u>		<u>Page</u>
1	CABLE CONFIGURATIONS .....	4
2	CASTLOK WIRE ROPE TERMINAL .....	5
3	GENERAL EPOXY-RESIN TERMINATION INSTALLATION ....	6
4	TERMINATION WITH MODELING CLAY .....	8
5	PREPARATION OF AMORPHOUS METAL CABLE SAMPLE ....	10
6	TERMINATION WITH HEAT-SHRINK TUBING .....	10
7	CROSS-SECTION OF FAILED STEEL CABLE TERMINATION ..	12
8	STEEL CABLE SPECIMEN AFTER SUCCESSFUL TENSILE TEST .....	13
9	CROSS-SECTION OF TITANIUM CABLE SPECIMEN AFTER TESTING .....	14
10	CROSS-SECTION OF AMORPHOUS METAL CABLE TERMINATION AFTER TESTING .....	15

## CHAPTER 1

### INTRODUCTION

The general function of end fittings, also referred to as terminations, is to allow the attachment of wire rope to a system in a manner that approaches 100 percent of the strength of the cable. This report addresses investigations made into the use of 'epoxy-resin' (epoxy) terminations.

### BACKGROUND

Epoxy terminations are generally applied by placing the unlaid, or untwisted, end of the cable inside a hollow body which is then filled with epoxy, capped, and allowed to cure. The cable is unlaid to allow for maximum area of adhesion. The termination body is generally shaped so as to take advantage of mechanical holding power as well. This system can result in a termination that does not risk plastic deformation of the cable nor apply stress concentrations. Furthermore, it promises enhancements in the realms of electrochemical and stress corrosion as well as eliminating the problems resulting from tolerancing which are inherent with swages.

### REPORT OVERVIEW

It was desired that the termination be able to work with cable diameters in the vicinity of .062 inch to .100 inch, develop 100 percent of the cable strength in fatigue as well as tension, and be able to withstand long term storage and long term seawater exposure. Other considerations included producability and reliability. Also destructive and non-destructive testing, conducted in the laboratory and in the field, was of concern.

The full investigation of all these concerns was beyond the level of this effort. This report describes a small set of samples which underwent tensile testing, the purpose being to document that work so that it may be effectively continued when resources become available.

## CHAPTER 2

### PREPARATION OF SPECIMENS

#### MATERIALS

Samples were made using steel, titanium, and amorphous metal cables whose tensile strengths ranged from 900 lbf to 1200 lbf. For clarification, cables are considered to be made of wires which are twisted into strands. The strands are then twisted into cable. For example, a 3x7 construction denotes a cable made of three strands each containing 7 wires (see Figure 1). The steel cable was a 1x7 construction, swaged and aluminized, with a diameter of .093 inch. The titanium cable was a 3x7 construction, swaged, with a diameter of .098 inch. The amorphous metal cable was a twisted 7x19 construction with a diameter of .062 inch. Here, 'swaged' means that when the strands and cable were constructed, they were run through a die to compact them, 'aluminized' refers to the fact that the cable was given a thin aluminum coating, and 'twisted' means that the wire and strands were not preformed (i.e., bent into a wave) before they were twisted together.

Research was done to find epoxy terminations compatible with .062 inch to .100 inch diameter cable. Terminations for .125 inch cable were the smallest found. Those used, appear under the trademark Castlok, a registered trademark belonging to Loos & Company, of Pomfret, Connecticut (see Figure 2). Each termination cost roughly four dollars and included the termination body, thread-on eye, epoxy resin and hardener, and instructions. Delivery took place within 30 days, except where items were out of stock and required 60 days.

#### METHODOLOGY

The installation instructions require that the termination body (henceforth referred to as 'body') be slipped over the end of the cable which is then unlaid and cleaned. The body is then pulled back up to enclose the end of the cable, filled with epoxy, and the eye threaded into its free end (see Figure 3). At room temperature, the working time of the epoxy is roughly one hour and the cure time is 24 hours.



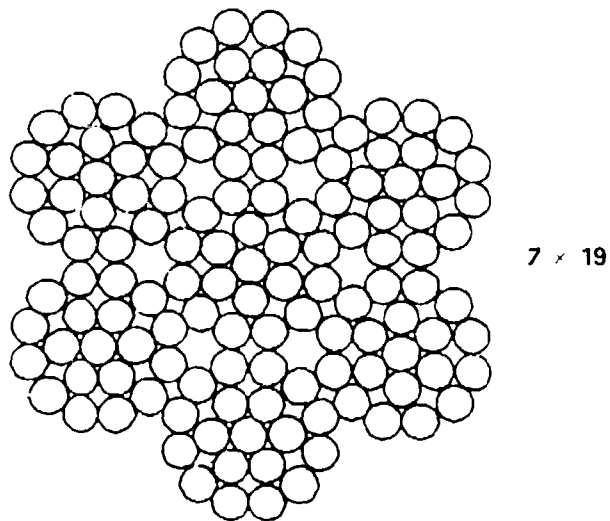
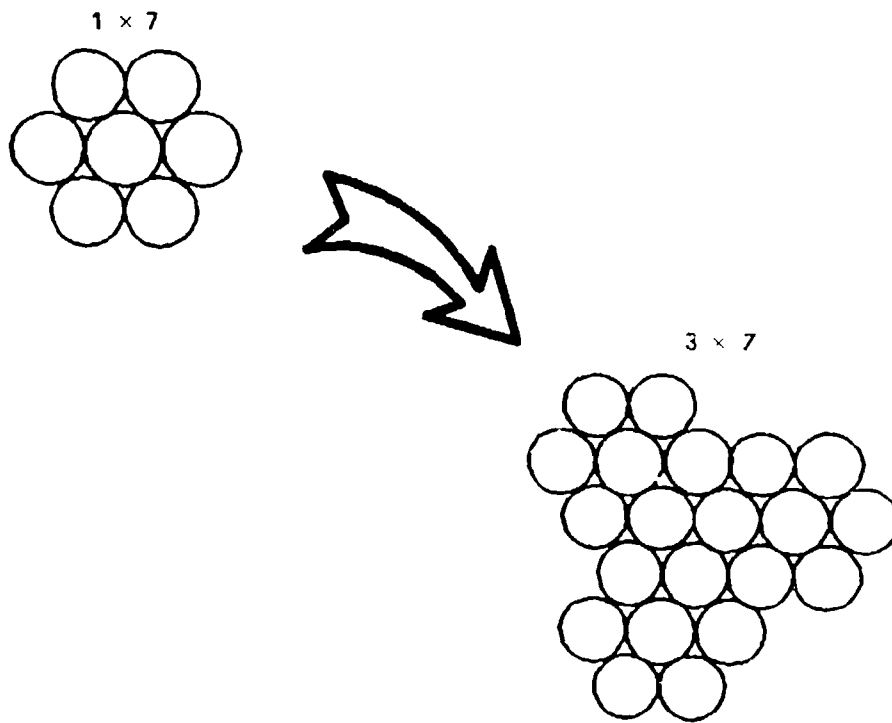


FIGURE 1. CABLE CONFIGURATIONS

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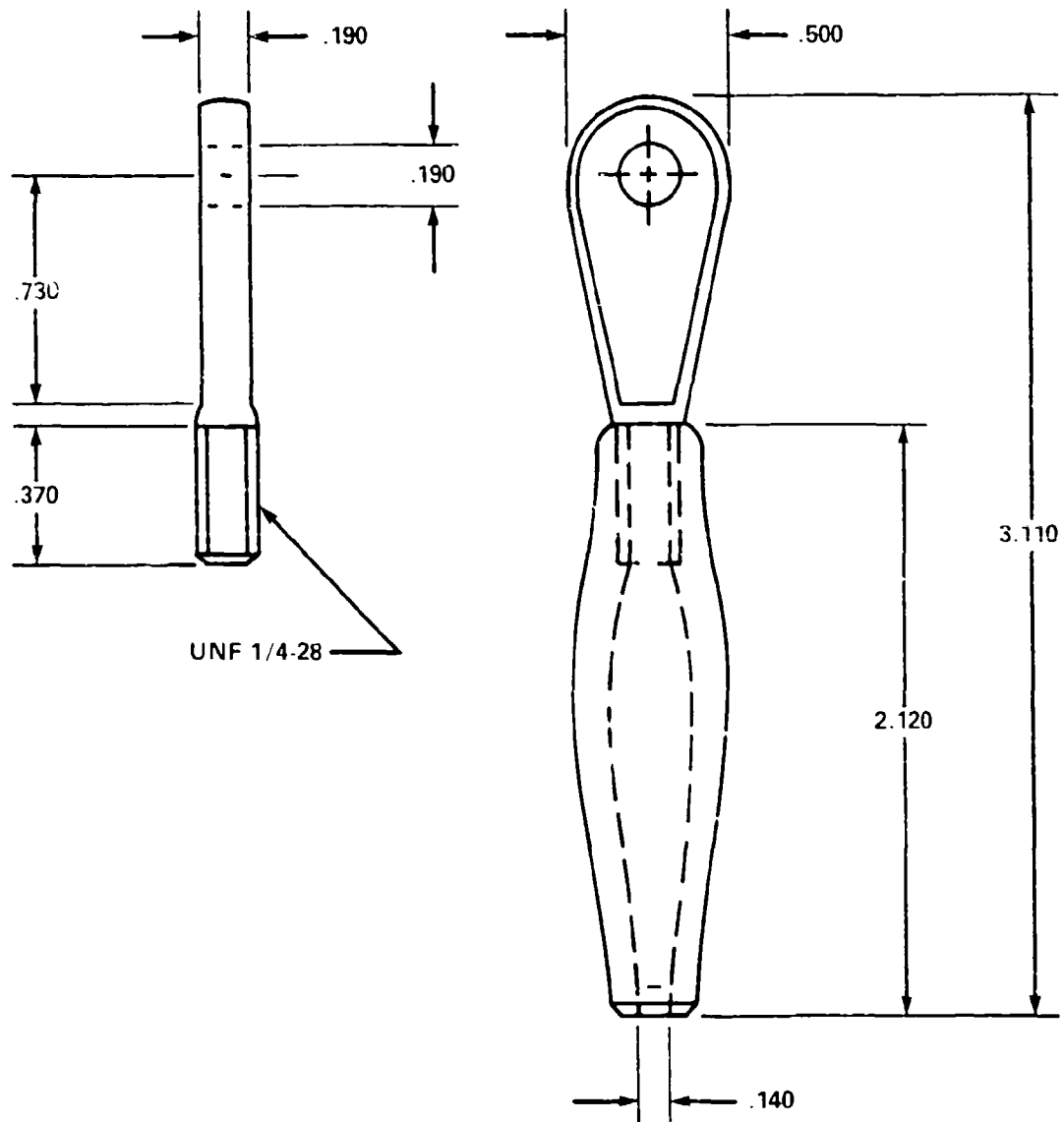


FIGURE 2. CASTLOK WIRE ROPE TERMINAL

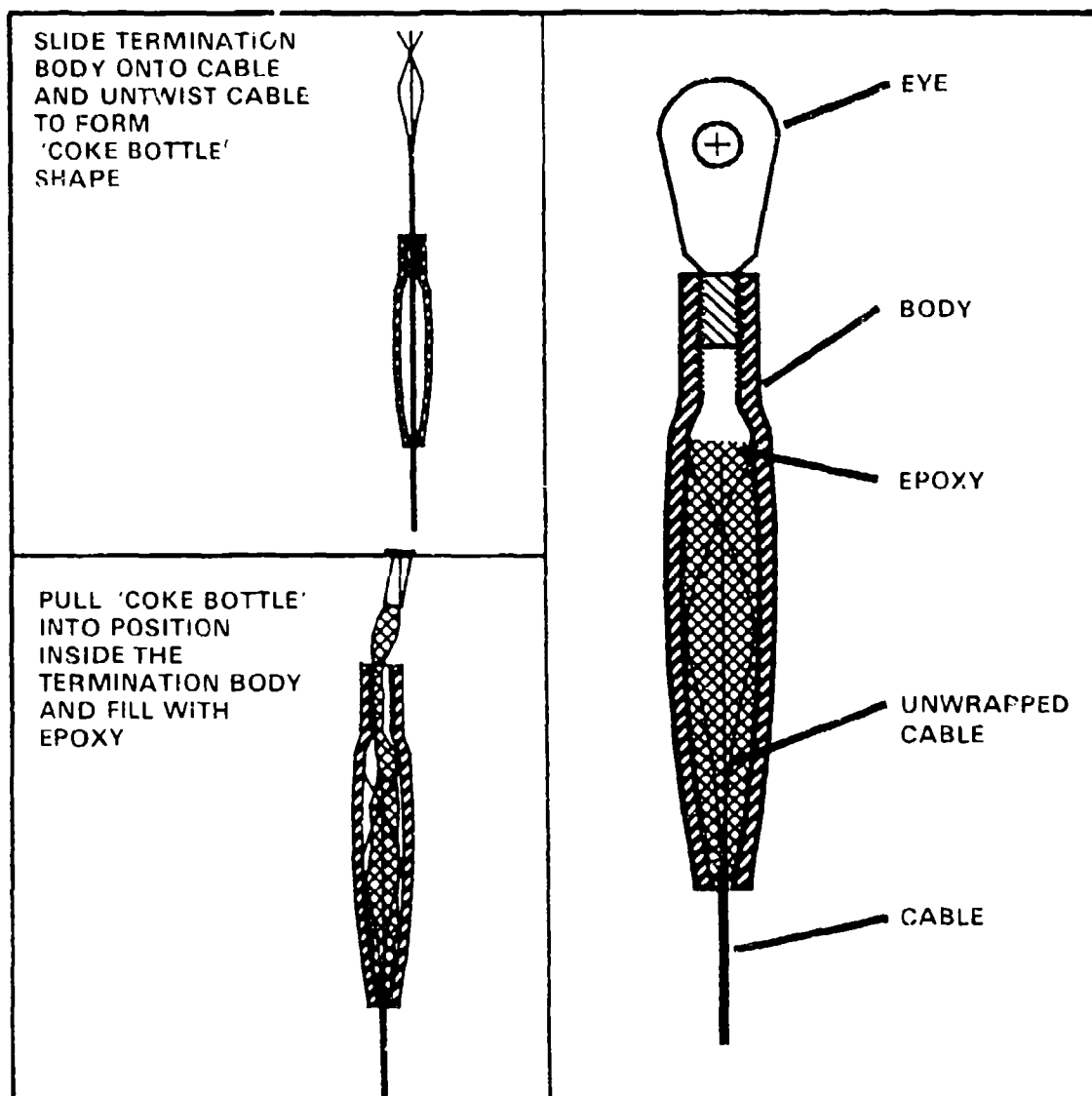


FIGURE 3. GENERAL EPOXY-RESIN TERMINATION INSTALLATION

## General

It is desired that the cable be uniaid to form a 'coke bottle.' This is done by twisting the end of the cable in the opposite direction from which it was laid. It is assumed that the cable was preformed, meaning that the wires were bent into a wave, so that when the cable is untwisted, the wires bend out from the central axis of the cable and then back in, forming a hollow bulb, which is termed a 'coke bottle.' In the 'coke bottle,' all the wires are separated, this increases the surface area available for adhesion. When the 'coke bottle' is pulled back into the termination body, it coincides with the belly of the body so that when epoxy is added a fairly uniform matrix of wire and epoxy is created. The belly assures that this matrix will not be able to move relative to the body.

The body is held vertical with the cable coming out of the bottom and epoxy is poured into the top. Although the newly mixed epoxy exhibits a great deal of surface tension, it has a fairly low viscosity. The characteristic of surface tension tends to make it cling to surfaces rather than just flow out through the bottom. The low viscosity allows the epoxy to fill in voids that occur when the body is filled. Once the body is filled, the eye is threaded into the top of the body. This forces epoxy down and out of the bottom of the body. If this does not occur, then the eye is removed, the body refilled, and the eye replaced, until epoxy appears at the bottom. The hole through which the cable exits the body is sized slightly larger than the cable diameter suggested for use with the termination. This, along with sealing the top of the body with the eye, prevents the epoxy from flowing out the bottom while allowing some epoxy to run between the cable and the body, which, when the excess is wiped off, forms a fillet against the cable.

## Specific

The use of the terminations with the cables previously mentioned required some adjustments. All the cables were significantly smaller in diameter than the .125 inch for which the terminations were designed.

Steel Specimen. The first sample was made with steel cable approximately two feet long. Being a 1x7 cable of relatively thick wires, it was easily formed into the 'coke bottle' shape by hand, cleaned in safety solvent, dried with acetone, and pulled into the body. The body was then mounted vertically in a vise with the cable hanging free. When the epoxy was added, however, it tended to flow out the bottom due to the .093 inch diameter of the cable. A thick ring of modeling clay was wrapped around the area where the cable emerged from the body, not only to prevent the epoxy from flowing out, but also to hold the 'coke bottle' in the middle of the body (see Figure 4). Terminations were installed on one end of the cable samples and allowed to cure overnight. The procedure was repeated the next day for the other end of the samples. This method worked well with the exception of one termination. Here the epoxy seeped up between the clay and the body allowing the clay to slip off the body, causing the cable to fall about one half inch.

Titanium Specimen. The second sample was made with a two-foot long titanium cable. The titanium is a 3x7 construction of relatively thin wires. It was significantly more difficult to form the 'coke bottle' with the three strands and then untwist the ends of each strand to a 'broom' as required by the instructions. A pair of needle nosed pliers was used to separate the wire. The cable was cleaned in safety solvent and dried using acetone. When the 'coke bottle' was pulled into the body, it

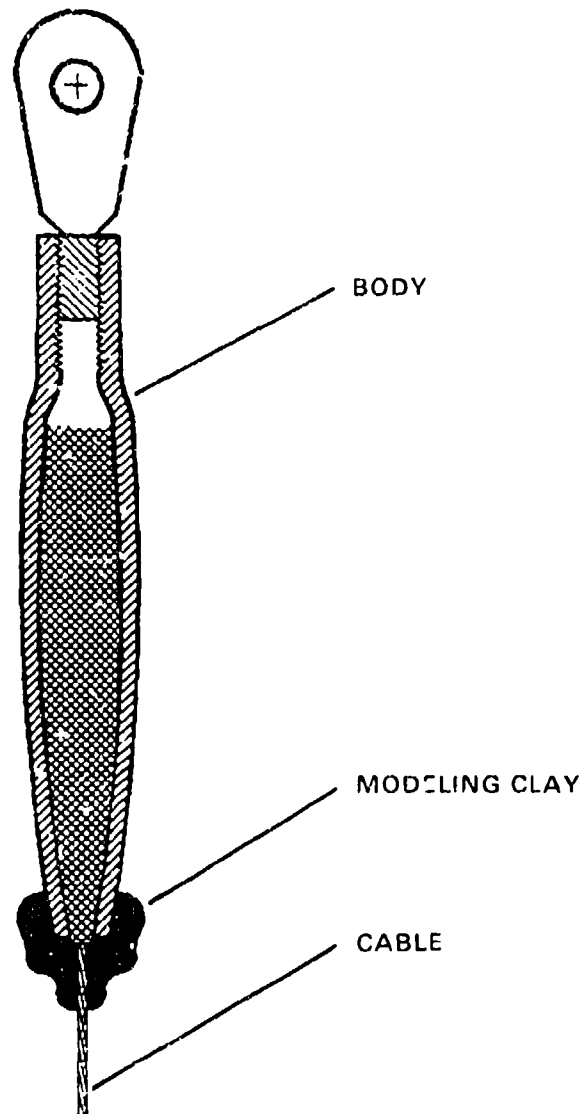


FIGURE 4. TERMINATION WITH MODELING CLAY

was apparent that the overall diameter of the 'broom' ends was greater than the threaded opening at the top of the body. This required that the cable be pulled into the termination very carefully. It was probable that some misalignment occurred to the 'coke bottle' when it was pulled into the body, however, observation into the top of the termination revealed that the ends were still separated and evenly distributed across the inside of the termination. The rest of the procedure repeated exactly what was done with the steel cable. Since the titanium cable is only .005 inch larger in diameter than the steel cable, the modeling clay was used again, this time with no slippage.

Amorphous Metal Specimen. The next three samples were approximately one foot long and made of amorphous metal cable. The cable was not preformed or pulled through a die. Because of this, it tended to curl into a helix roughly two inches in diameter, and when cut, it tended to unravel quickly. Several concepts were considered for holding the cable intact when samples were cut. In the end, epoxy resin was applied to the cable with a mixing stick, the strands were partially separated to allow the epoxy to flow around each, laid back into the cable, and left to cure overnight. The samples were initially prepared as shown in Figure 5, taking note that the epoxy bands were properly placed and thin enough to fit through the bottom hole of the body. When the epoxy bands were cured, the sample was pushed up through the bottom of the body until the epoxy at the end of the sample could be cut off, allowing the end to unravel.

The cable was a 7x19 made of very fine wire. Since the wires were not preformed, a 'coke bottle' could not be formed. Instead, the best possible attempt to make a 'broom' of the cable was made, however, there are 133 wires in a 7x19 cable, therefore this could not be done to perfection. The 'broom' was then cleaned in methanol, allowed to dry, and pulled into the body. The cable had a diameter of .062 inch, half the .125 inch for which the terminations were designed. To keep the termination's epoxy from flowing out the bottom, and to hold the cable in place inside the body, shrink tubing was employed (see Figure 6). Ideally, the tubing would have fit over the bottom of the body and been able to shrink enough to seal around the cable, but tubing with this high a ratio of shrinkage was not readily available. Instead, a small diameter tube, roughly a half inch in length was shrunk into position around the cable where it emerged from the body, and a larger diameter tube, roughly 3/4 of an inch long, was slipped halfway onto the body so that it could be shrunk over the body and down around the smaller shrink tubing, forming a seal around the body and the cable and holding the assembly together.

The desired gage length on these samples was roughly 5 inches. It was decided to attach the termination to the other end at the same time by clamping the two terminations in a vise and letting the cable form a "U" between them. This was done by slipping on another pair of heat shrink tubes and repeating the above procedure for the other end of the cable. In this way, both ends of the cable were terminated in one day rather than two.

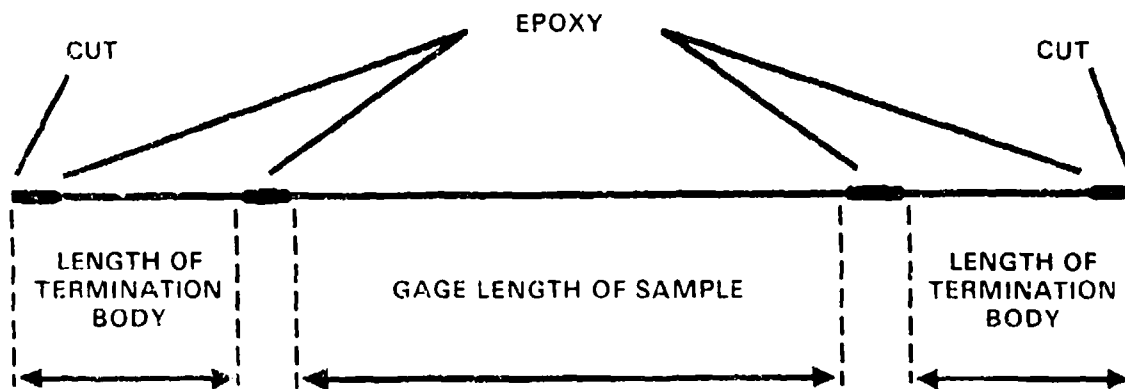


FIGURE 5. PREPARATION OF AMORPHOUS METAL CABLE SAMPLE

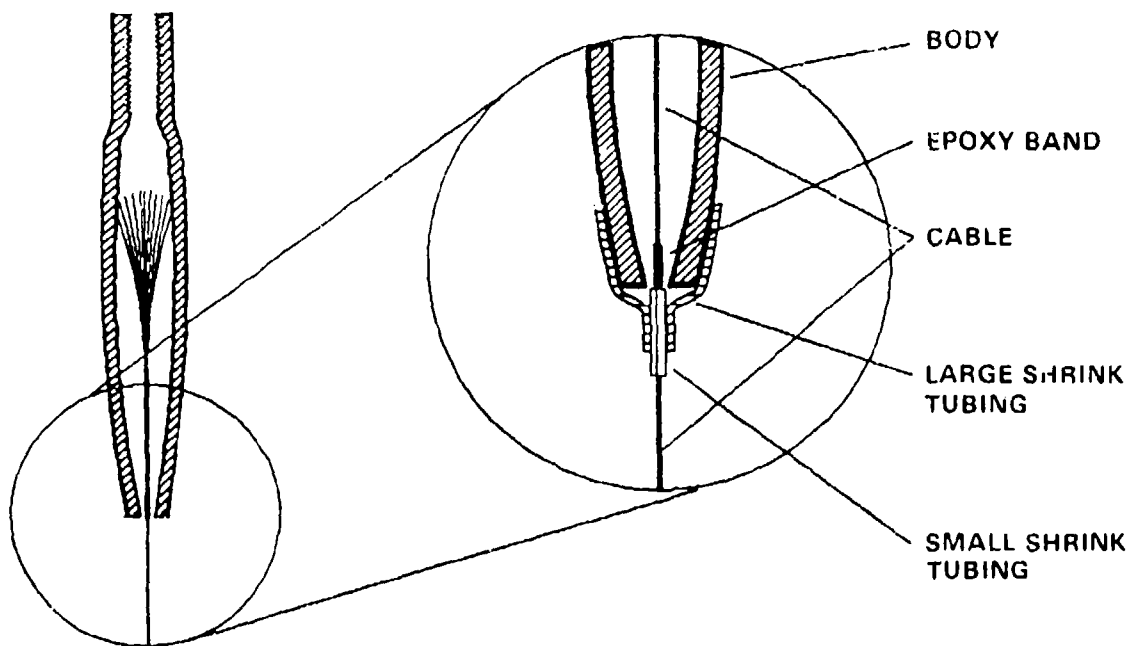


FIGURE 6. TERMINATION WITH HEAT-SHRINK TUBING

## CHAPTER 3

### TESTING AND EVALUATION

#### TESTING

Only tensile testing was done.

Steel Specimen. The steel cable sample was pulled to 795 lbf. At this load the cable pulled out of the upper termination before breaking. The failed termination was milled to reveal its cross-section along the long axis (see Figure 7). Observation showed that the 'coke bottle' had slipped very far down in the body. This was the termination where the epoxy was observed to have seeped between the body and the modeling clay, allowing the cable to slip down. With insufficient adhesive area, the cable simply pulled free of the epoxy. A mechanical swage was installed on the failed end and the sample was tested again. The load was brought up to 920 lbf and held for one minute. As the load was increased again, there were 'pops' at 975 lbf and 1150 lbf due to the stretching of the cable. Failure occurred at 1420 lbf in the middle of the gage length (see Figure 8).

Titanium Specimen. The titanium cable sample was loaded to 900 lbf and held there for one minute. Failure occurred at 938 lbf in the middle of the gage length. Figure 9 shows one termination of the sample which was milled to reveal its cross-section.

Amorphous Metal Specimen. The amorphous cable samples failed at 885 lbf, 895 lbf, and 945 lbf. Due to the complexity of the cable, the installation of the terminations showed some faults. In some cases, the cable had unlaid itself slightly and/or emerged from the termination off center from the hole in the body. Only the specimen which took load up to 945 lbf was free of these faults, and had failure occurring in the middle of the gage length. Figure 10 shows one of the terminations of this sample which was ground to reveal its cross-section. The other two samples both failed where the cable emerged from the body.

#### EVALUATION

The forming of the 'coke bottle' became more difficult as the complexity of the cable construction increased, and with non-preformed cable, it was not possible. In general, the 'coke bottle' is easy to form with a 1x \_\_\_\_ cable construction. With a 3x \_\_\_\_ or 7x \_\_\_\_ construction the strands were formed into a 'coke bottle' and their ends were formed into a 'broom'. This is a relatively more complex task. Though the terminations were designed for cables larger than those used, the larger body and top opening allowed for the handling of more complex cable constructions, without collapsing them.



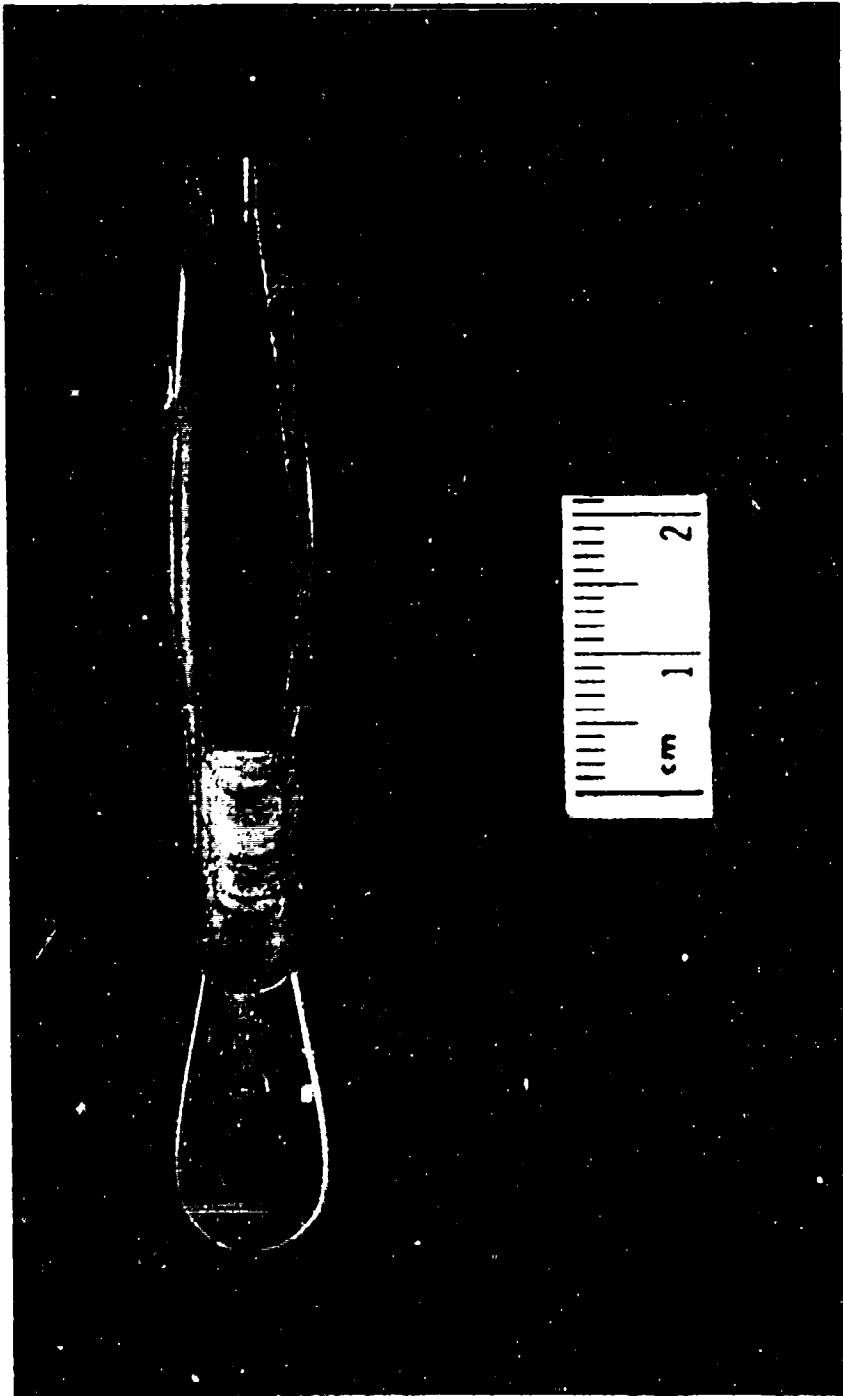


FIGURE 7. CROSS-SECTION OF FAILED STEEL CABLE TERMINATION

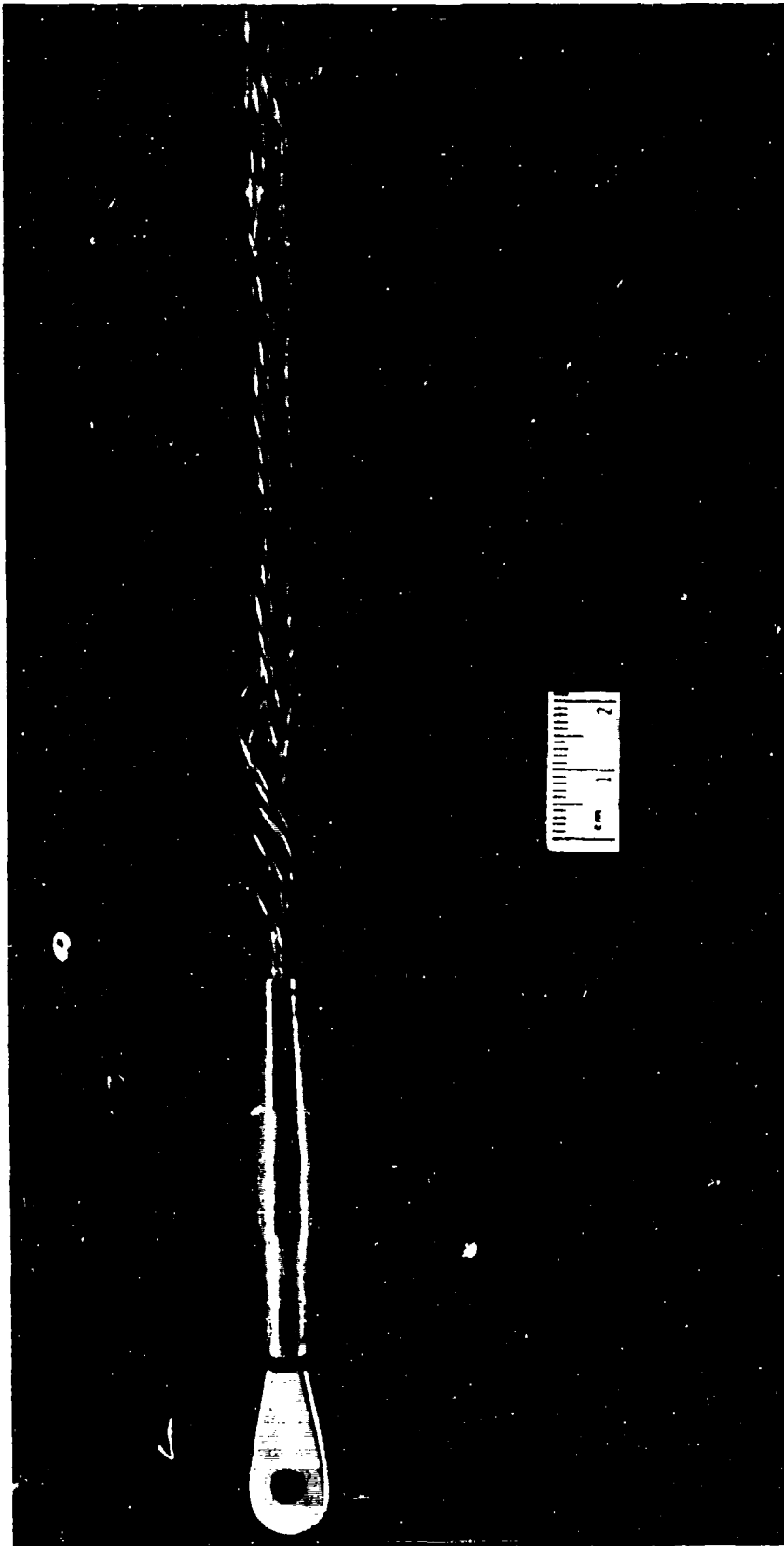


FIGURE 8. STEEL CABLE SPECIMEN AFTER SUCCESSFUL TENSILE TEST

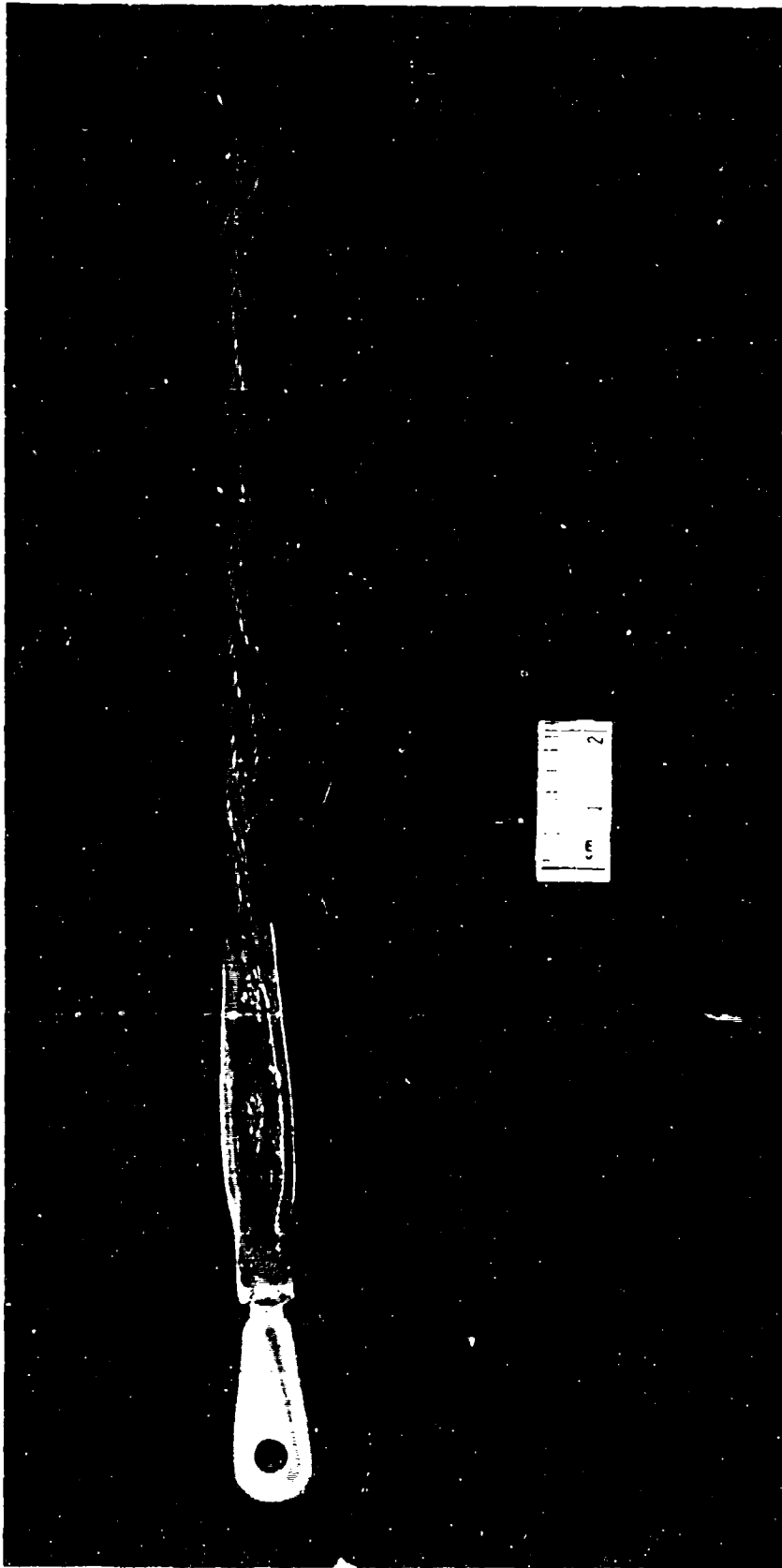


FIGURE 9. CROSS-SECTION OF TITANIUM CABLE SPECIMEN AFTER TESTING

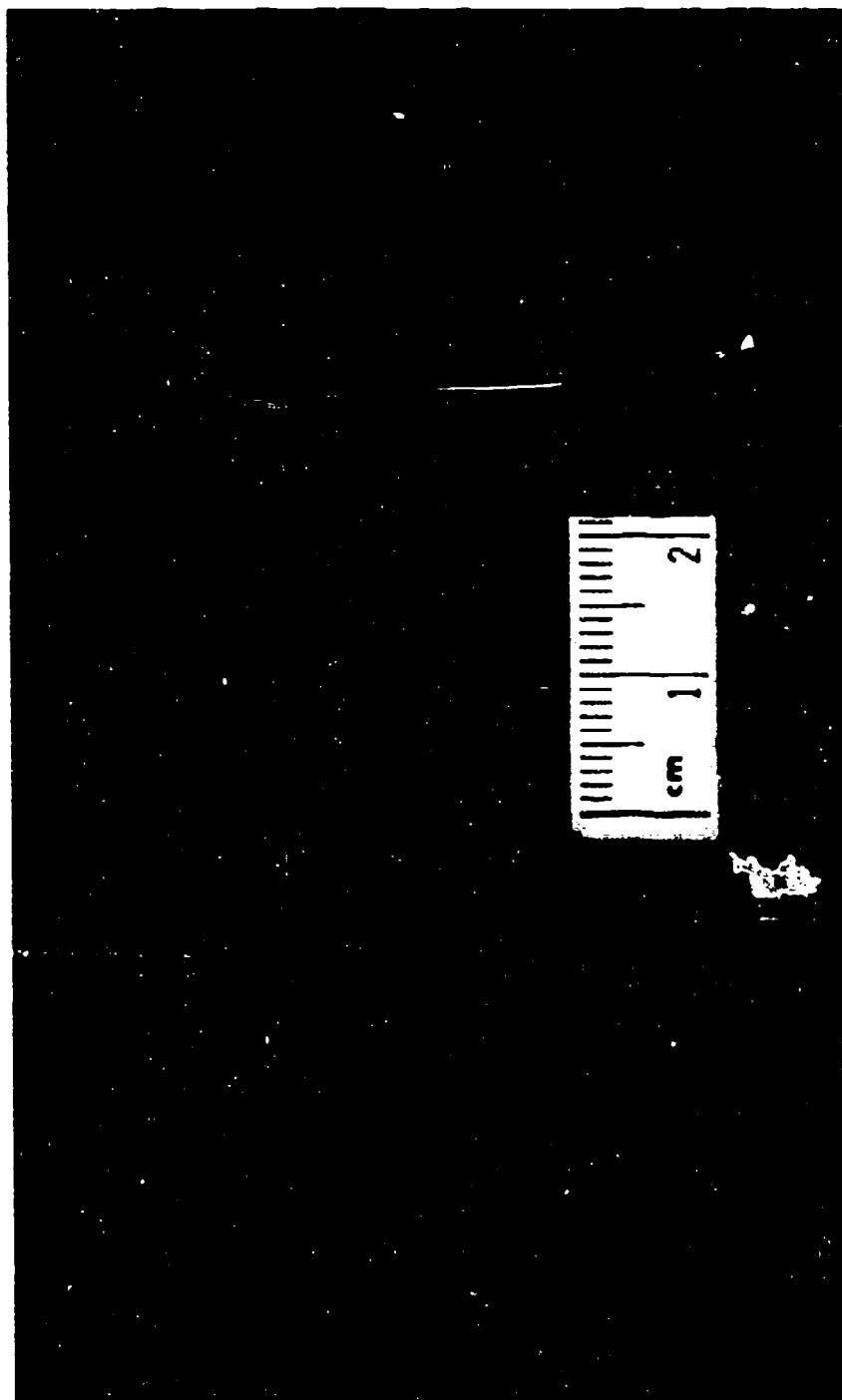


FIGURE 10. CROSS-SECTION OF AMORPHOUS METAL CABLE TERMINATION AFTER TESTING

Cleaning the cable and terminations with methanol proved to be a simple, effective, one-step process.

Potting these terminations required that several factors be controlled: the 'coke bottle' had to be retracted into the body intact and in the proper position, the cable had to be axially centered and held in place, and the bottom of the termination had to be sealed to prevent excessive loss of epoxy. This was accomplished with modeling clay and shrink tubing. The modeling clay was not considered satisfactory because of the slippage that occurred when epoxy seeped between it and the body. The shrink tubing was an improvement but required multiple steps and allowed the cable to set off-center from the body axis. In some cases, the shrink tubing around the cable could serve to axially center the cable by allowing it to rest a fraction of an inch inside the body. A device which could be easily installed to hold the cable and body together in proper orientation would simplify and improve the process. The working time of the epoxy was sufficient and bubbles rose to the top in all cases.

For non-preformed cable it was necessary to assure that the cable would remain intact outside of the body. In lieu of a 'coke bottle,' it was important to 'broom' the strands as much as possible to increase adhesive area.

In all cases, the epoxy adhered very well, even when there was little adhesive area on the cable.

Where terminations were cut along their axis, it was noted that milling caused distortion and tearing between the wires and the epoxy. Using a mill for the coarse removal of material, then switching to a grinder for the final cutting of the cross-section, as was done for the amorphous metal samples, provided a cleaner view, but attention had to be paid to keeping the temperature below 400°F to avoid melting the epoxy.

## CHAPTER 4

### CONCLUSIONS

The epoxy terminations provide an efficient way of attaching end fittings to the small diameter cables used in this study.

Compared to other termination options, the epoxy terminations appear to be superior. Other types of terminations such as clamps, compression fittings, and swages apply stress concentrations to the cable. The 'Chinese finger' type requires a fairly long gripping area. In many cases dissimilar metals are in direct contact, enhancing electrochemical corrosion, especially in a saltwater environment.

The epoxy terminations worked well with different composition cables of varying structure and without necessitating the design of a specific termination for each cable. Though some assembly problems were experienced, they appear to be readily solvable. In general, the epoxy terminations provided a system with 100 percent of the tensile strength of the cable.

Epoxy terminations are especially promising in situations where small diameter cables of very fine wires require end fittings that do not apply stress concentrations.

## CHAPTER 5

### RECOMMENDATIONS

It is recommended that research into epoxy terminations for small diameter cables be continued as it appears possible that they may offer a solution to many of the weaknesses inherent in other types of terminations.

#### PREPARATION OF SPECIMENS

A predictable and repeatable system to create the 'coke bottle' or 'broom' shape should be investigated. A companion effort would be the utilization of X-ray technology or an equally effective non-destructive method to ensure the existence of that shape just prior to pouring the epoxy.

A significant enhancement would be the creation of a clamping/sealing device that holds the termination in the vertical position while keeping the 'coke bottle' and axial orientation of the cable as well as sealing the termination/cable interface to retard the loss of epoxy. An example of such a device might be a test tube stand with appropriately modified clamps. This could be extended to allow the application of terminations to both ends of the cable at the same time.

A secondary enhancement would be the investigation of oven curing the terminations. The Castlok instructions point out that if the temperature is increased from 75°F to 150°F, the full cure time is reduced from 24 hours to 2 hours.

In the interest of completeness, a market survey should be conducted to verify whether or not smaller terminations are available.

#### TESTING AND EVALUATION

Since only tensile testing has been done, further testing is necessary before these terminations can be incorporated into designs with confidence. Testing was certainly carried out to certify the production of these terminations. Records of this testing should be acquired. It is strongly recommended that the specific application of small diameter cables which must withstand long storage periods in a variety of environments as well as extended exposure to seawater be investigated.

Torsion, fatigue, electrochemical and stress corrosion, thermal cycling and thermal shock, degradation through aging, and impact testing are all of interest to this application. Fatigue testing should be carried out in several modes so as to simulate a mooring cable environment, including torsional, axial, and lateral. Some of these tests should also be carried out in a saltwater bath. Corrosion testing in salt water, should be carried out on the termination body and threaded end fitting themselves, as well as in conjunction with the various cable materials and other

fittings that might provide an ion path. Thermal tests of several types should be investigated; for example, a long duration, moderate temperature range test to model storage conditions and a short duration, extreme temperature range test to model deployment scenarios. From the Castlok instructions, it is known that the epoxy is sensitive to thermal effects. Modeling the most extreme thermal environments produced by the application and studying its effect, perhaps in conjunction with impact or exposure to seawater would provide insight as to how these terminations might be incorporated into design.

It is understood that the battery of testing described will incur considerable cost, however it can be done as relatively small funds become available as opposed to the large sums required for full scale tests such as endurance fields, etc. Should large sums be available, it is probable that larger scale tests could provide results from several of the above mentioned tests at once.

Finally, investigations into the repeatability of termination properties should be carried out. It would be reasonable to assume that these may be limited to tensile strength. A portable tester, capable of loading a termination/cable system to a desired level would facilitate this study while finding many other applications, both in the laboratory and in the field.



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